

**Framework for Research Leading to Improved Assessment  
of Dredge Generated Plumes**

**By**

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- 2. Framework for research – paper presented at WEDA 24**

## **1. INTRODUCTION**

The aim of the work was described in the 1<sup>st</sup> Interim Report. The 2nd Interim Report describes the work done up to January 2004.

HR Wallingford was given notice on 4 February 2004 to stop work on the project due to budget constraints. Notice to recommence work was given on 6 April 2004. This involved a rescheduling of deliverables and it was agreed that an interim report (this present report) would be produced at the end of July 2004 and the final version of the research framework at the end of August 2004.

This third interim report thus covers the period from 6 April to 31 July 2004. During this period the ACCORD process that was initiated in London in October 2003 continued with a meeting in Vicksburg on 20 May 2004, combined with a co-operation meeting to review progress on the contract on 21 May 2004.

There was a disappointing representation of other organisations at the ACCORD meeting so it was decided to hold another meeting at the forthcoming Western Dredging Association's annual conference to be held in Orlando in July where it would be guaranteed that many relevant organisations would be present, particularly the dredging contractors and the ports sector.

Also it had been previously agreed that a paper about the research framework would be presented at WEDA as a way of raising awareness and getting feedback on the draft framework.

The paper was written and presented at WEDA (and incidentally was awarded a certificate for the "best technical presentation" at the conference). With the co-operation of the conference organiser a special meeting was arranged to present the draft ACCORD charter and invite support.

Following the conference a period of one month has been allowed for comment on the paper before finalising the framework for research. This is scheduled for 30 August 2004.

This report has extensively drawn on notes prepared by Jim Clausner and Tom Borrowman of ERDC, for which the author is grateful.

## **2. COMBINED ACCORD MEETING AND ERDC CO-OPERATION MEETING 20 – 21 MAY 2004**

It had been the intention to hold the second meeting of ACCORD on 20 May and the Co-operation meeting on 21 May. Because there were no representatives from organisations other than those involved in the co-operation meeting it was decided to combine the two agendas in order to avoid repetition.

The meeting was attended by:

Jim Clausner

E ERDC-CHL-MS

(Project Point of Contact)

Borrowman, Thomas	ERDC-EL	(Meeting Co-ordinator)
Doug Clarke	ERDC-EL	
Craig Swanson	ASA	
Don Hayes	The Utah University	
Trudy Estes	ERDC-EL	
Joe Gailani	ERDC-CHL	
Hans Otten	Rijkswaterstaat (Netherlands)	
John Land	Dredging Research Ltd. (UK)	
Stephen Maynard	ERDC-CHL	
Neville Burt	HR Wallingford (UK)	(Project Manager)
Paul Schroeder	ERDC-EL	
Jarell Smith	ERDC-CHL	
Chuck Dickerson	ERDC-EL	
Jez Spearman	HR Wallingford	(modeller)

## 2.1 General overview

Neville Burt presented a summary of the 1st ACCORD Meeting in London in October 2003. (This is given in the 2<sup>nd</sup> Interim Report).

The main points in discussion were:

### Organisations we should try to get involved

- Dredging companies in the US
- NMFS or NOAA but it could be difficult; Mike Ludwig was suggested as a possible contact. (A demonstration is planned on Grass River in Messina)
- Ports sector. We should show them we can help them reduce windows. Don Hayes had a meeting with some ports on resuspension before Sep 11, not much since then.
- USGS may have an interest. SF Bay, Dave Shoalhammer – has published on resuspension in Tampa, Corpus Christy, SF Bay. Doug Clark knows him through LTMS in SF bay. We should invite him to be involved in ACCORD.
- Universities, e.g. LSU. Invite Danny Reible and Louis Thibodeaux. TAMU now has a dredging flume. May be potential to research some things we can't look at in the field. Invite Bob Randall to participate. Jarrell will check on flume dimensions. [Later note: Bob Rendal gave a presentation about the flume at WEDA 24]
- DAMOS program – headed by Tom Fredette
- MMS might be interested in getting data in sand.
- EPA should be interested with regard to collection of data on superfund projects.

### Other work we know about:

PANYNJ? had sponsored some plume studies with SAIC, dipper dredge. May have sponsored some other work

Don Hayes is writing performance standards for contaminant dredging for Hudson River. Worries they will be miss-applied.

## ACCORD

There was a wide ranging discussion on the aims, possible funding agencies and possible ways of organising it. Following the meeting a Draft Charter was produced (Appendix 1).

It was agreed to organise a special meeting of ACCORD at WEDA 24 (Report in Chapter 3)

### **2.2 Presentation on the plume tracking effort at Providence River (Doug Clarke)**

It had not been an ideal situation at end of FY03. It was the wrong time and the dredging was in a not ideal place, further it involved dredging a CAD cell. However they did get some good data on the protocol. Most of the material went into the pit, not down the estuary.

They did the bubble test and concluded they were able to get close to the bucket.

A further attempt was made in April 04, while the contractor was doing maintenance dredging. But the dredge kept changing location on an hourly or daily basis. Measurements were made at two locations, Sabin Reach, Bullock Point. It was a steep walled channel with adjacent flats. Only in southern point do you get some flats. The surveyors ended up chasing flood plumes. They achieved 50 m spacing between lines.

The protocols were followed, repeated lines, replicate lines in successive distances in time but so far have not had time to analyze the data. They believe they have several good flood surveys in. Some features of the conditions were:

- Dredging against a side slope.
- There was some fresh water outflow on the surface.

They had anticipated an open bucket, but it was actually a large closed bucket. The Contractor tried to overfill the bucket to increase production. It was a 26 cy open bucket, but he had added volume to enclose the bucket. The fill material came out of ports and seams.

The exercise was recorded on videotape that was thought to be very useful. Details concerning the water sample and gravimetric data were:

- Used LISST to get grain size data in the plume
- Used LISST as water quality sampler at different locations in the water column. Took water samples synoptically with LISST.
- LISST went from 2.5 to 500 microns.
- Will try to get grain size from the filters on water samplers.

There followed a discussion on the complexities of dynamic calibration of instruments measuring suspended solids concentration.

### **2.3 Presentation of the Panama City Project (Doug Clarke)**

The dredger was a 24-inch hydraulic cutterhead dredge with pipeline discharge to a natural basin. In the area there were lots of sea grass beds. To represent the flowfield they used ASA's Hydromap. Hydromap captures eddies that were seen in the current meter measurements. SSFATE appeared to underpredict the deposition rate so the values used for settling rates were increased. The problem was likely to be due to more sand being in the material than was originally expected.

It was generally thought to have worked well and provided data to FLA DNR.

## **2.4 Presentation of the Upper Chesapeake Bay Project (Doug Clarke)**

The project was at Upper Chesapeake Bay, Brewerton Cutoff. The dredging plant was an open bucket. Two dredges were working at the same time, one mile apart.

EA Engineering is doing some sampling – they should have sediment characterisation. Initial SSFATE predictions thought to be very conservative so the model was recalibrated based on field data. For the source term they used ½ to 1 percent of the volume (weight?) dredged. The main controllable variables in the model predictions are the source term and the settling coefficients.

There followed a discussion on the validity of making the adjustments. Most attention was given to the process of flocculation.

## **2.5 Presentation on 2002 Hopper Dredge Monitoring Effort in Rotterdam (John Land)**

HR and DRL have previously reported the exercise that took place in June 2002 using the trailing suction hopper dredger Cornelia.

The high cost of testing the larger than expected number of samples caused the delay between obtaining the data and analyzing it. The purpose of the exercise (carried out under the Dutch funded TASS project) was to test and further develop the trailer dredger protocol. A lot of effort and manpower (or more precisely woman power) had gone in measuring overflow losses. Other objectives had been to study the dynamic plume and monitor the far field plume in order to assist with calibration of dynamic plume model.

The Sediview calibration had been difficult because it was not possible to obtain water samples in draghead-generated plumes. The decision was made to take calibration data from the decaying overflow plume and assume they were the same. Considering the circumstances, the feeling was that we had obtained fairly good results.

It was only possible to observe the draghead plume data higher than 1 meter above the bed due to ADCP measuring limitations. In sand, the draghead does not bulldoze, it sits on top of the bed and takes off top 20 to 30 cm per pass. When dredging mud, the draghead sinks, and the sediment wedge that is pushed (bulldozed) builds up. With increasing dredge speed there is a large increase in sediment release.

In summary it was thought that the exercise was a success:

- The draghead data look reasonable. It had never been done before and the results were the expected order of magnitude
- The dynamic plume data looked good. This too had never been done before and the results were much as expected.
- There were some overflow data problems (samplers to be resolved)
- The Measurement Protocol needs refining

## **2.6 Presentation of the Research Framework for Sediment and Contaminant Release and their Impact (Neville Burt)**

Neville Burt presented the most recent version of the draft Research Framework. The first draft was included as an appendix to the second Interim Report. The final version will be submitted in August. The version presented was substantially complete but still required comment and editing.

A summary version was to be presented as a paper at the WEDA conference in Orlando in July 2004. The paper is attached to this report as Appendix 2.

There was a discussion about how best to use the Research Framework. The suggestion adopted was that a White Paper would be produced that can be used by upper management, headquarters and EPA to decide on investments in research. It should help to focus research in DOER and potentially improve goals to EPA funding. It was agreed that Don Hayes would produce the first draft based on the existing report.

## **2.7 Presentation of Simple Source Models (Don Hayes)**

Don stressed that it is difficult to get the data you need. He was worried about giving out guidance based on a small amount of data. In January 04, he produced a second version, but still had a long way to go. He is also working on the framework mentioned in the previous section.

Much of the old empirical modelling Don had attempted was too difficult. He now recommends keeping it simple – resuspension factor times a sediment removal rate.

Don starts with a characteristic dredging operation then applies:

- Factor that accounts for changes in environment and operations.
- Where possible used physics
- Where not possible – used common sense
- Adjustment factors applied for, cycle time, sediment characteristics, debris, bucket size.

Some things we don't know well enough – e.g., material properties. Paul and Don have used in-situ moisture content vs. liquid limit. This is an area we should look at first.



So far they have not done a sensitivity analysis and this should be included. Need a reasonable range for of the parameters.

It would be useful to model the Boston Harbor and compare the results to Doug Clarke's recent measurements. John Land, could provide some data to test model.

## **2.8 Presentation on ship induced resuspension (Steve Maynard)**

It had previously been pointed out in discussions that it is not only dredgers that create sediment plumes and that ships and tugs also generate large amounts of resuspension. Steve presented the following main points:

1. Effects of ship movement
  - a. Forces on moored ships
  - b. Safety
  - c. Environmental Effects
    - i. Propeller scour
2. Major area – bank erosion and protection
  - a. Blockage ratio important
  - b. Propeller speed important for resuspension
  - c. Large impacts due to transverse stern waves, can get up to 5 ft waves, 5 ft sec return currents
3. HIVEL2D model works well for currents and waves.
4. Shallow Draft Navigation on Upper Miss Waterway
  - a. Objective – resuspension on upper miss
    - i. Scale model – near bed velocity
    - ii. Used hot film anemometer to get bed shear stress.
5. Process to Define Bed Shear Stress.
  - a. Five Steps – most important is applied power. Don't assume 100 percent power is applied in most cases.
6. Put in context of dredging
  - a. Propeller wash from dredge itself.
  - b. ESTEX flume – potential to use for modeling
  - c. Problems in scaling in cohesive forces in sediments.
  - d. Physical modeling can help to visualize the process.
  - e. Pass on the calculation of resuspension from Brazil.

## **2.9 Tass Phase 3 (Hans Otten)**

SSB (the Dutch organisation funding Phase 3 of the TASS project) is planning to commission 5 sets of measurements on trailing suction hopper dredgers over the next 3 years (see report of first ACCORD meeting – Second Interim Report, Jan 04)

If big three dredging companies take on trailer dredging, who looks at other dredge types? The others are important (cutterhead, mechanical, etc). Perhaps ACCORD is a means to gain access to funding the other dredges. Hans has put together some costs John Land noted the need for a preset publicity scheme -. Dutch dredgers are very concerned about information released. What do we tell to who, who has access to the data?

## **2.10 Funding of future measurements and ACCORD**

- VBKO – still has an interest and can fund it's own interests
- SSB – funds trailer, also want to be involved and other aspects of Phase 3.
- Rijkswaterstaat will continue interest and fund Hans' involvement
- UK government interest.
- HR Wallingford need funding to maintain involvement.
- This fits into DOTS. Is it allowed to use DOTS funds for tech transfer?
- Joe Wilson and Bob Engler – need to approve.
- Internally can we find some aspects into DOER, but DOER funds should mostly be used for research.
- Paul can DOER fund some lab work?
- What are the PORTS doing?
- Partnering with a District.
- Monitoring budgets are likely to be constrained
- Jarrell – SF bay – dredging around highway construction. Paul potential to leverage projects.
- Need to have a center, talk to dredgers, Ports.
- Paul, ACCORD a research development technology forum, solicits government agencies, etc for membership, offer their projects for monitoring.
- Don H. – pitch to NSF – decide how to set up – gather funding. Let them pay to get it started. Maybe get some funds.

#### **2.11 Protocols and Availability**

- Keep track of who has got it.
- Acknowledge authorship and ownership.
- Have Tom Borrowman develop web site.

#### **2.12 Presentation of the Dynamic plume Model (Jez Spearman)**

This had been developed using funding from VBKO and MMS. MMS particularly The MMS final report is (will be) out on the web.

#### **2.13 Actions arising from the meeting**

1. Present ACCORD at the Western Dredging Association (WEDA) Annual Meeting in Orland, FL, 6-9 July 04. There was wide-spread agreement among participants to have a 1 to 1.5 hour session to educate resource agencies, dredging companies, and others on ACCORD.
  - i. Presenting, probably Jim Clausner and Neville Burt
    1. Background
    2. Status
    3. Solicit input, membership
  - ii. ACCORD poster and information will be available at the ERDC booth.
    1. Doug Clarke will make arrangements to have ACCORD poster created and flyer printed (and fund via DOTS)
    2. One page flyer will be drafted (similar to the ACCORD flyer used at London 03 Meeting).
      - a. Tom Borrowman responsible for overseeing drafting of flyer

- b. Neville Burt to take lead in actual writing of flyer.
- iii. Jim Clausner has contacted Larry Patella, Larry granted us permission to present ACCORD at WEDA. We need to decide on when (I suggest after the AM session Thursday July 8).

**Jim Clausner** will contact other US dredging companies in advance, and Tom Chase to get them up to speed on ACCORD and solicit their attendance at the meeting.

2. Distribution of PowerPoint Presentations from May 04 Meeting
  - a. Tom Borrowman will arrange to put PowerPoint Presentations on server for access by attendees.
3. Protocol Technical Note
  - a. Tom Borrowman will write
    - i. Burt, Land, and Otten to Review
    - ii. Second tech note or section to describe philosophy/recommendations for compliance monitoring
  - b. Target date for draft – early July ?
  - c. Goal to have tech note and protocols on web soon after WEDA.
4. ACCORD Web Site
  - a. Will set up on server in EL.
  - b. Links from DOTS/DOER/HR Wallingford/Rijkswaterstaat/Others
  - c. DOTS funds initial development
  - d. Goal to have Web site up shortly after WEDA
  - e. Borrowman to take first cut at site layout/content
5. Hayes Tech Note on Basic Resuspension Factors.
  - a. Hayes to meet with Borrowman and Schroeder on 26 May. Final tech note provided a couple of weeks after that.
6. Protocols
  - a. John Land will be updating.
  - b. Target date is soon after WEDA or Web site is up.
  - c. Hans Otten expressed strong desire to have list of persons downloading the protocols.
7. Framework
 

Goal is an 8 to 12 page whitepaper for upper level Corps and EPA managers to assist in making decisions on funding resuspension research. This document could also serve as background for ACCORD members in general, and particular those we are trying to persuade to fund monitoring activities. Burt and Hayes will modify/add to existing information to make first cut a white/paper. Neville's work to date will become an appendix, probably supplemented by information from Doug Clarke.

### 3. ACCORD SPECIAL MEETING AT WEDA CONFERENCE 8 JULY 2004

A special open session was held at the WEDA XXIV and Texas A&M's 36th Annual Dredging Seminar - July 6-9th, 2004 in Orlando, FL at which Neville Burt of HR Wallingford presented The Advice and Consultation Committee on Resuspension due to Dredging's (ACCORD) draft charter for input from government agencies, ports and harbors, dredging contractors, consulting engineers, and academia. The need for participation by these parties in ACCORD was then presented, followed by the solicitation of feedback from the audience.

ACCORD was formed by representatives HR Wallingford, Dredging Research Limited (both of the UK), the U.S. Army Engineer Research and Development Center (ERDC), the Rijkswaterstaat (Netherlands), and the Dutch consortium of dredging contractors (VBKO) with the main goal of supporting research to develop the ability to predict resuspension from all the major dredge types and speciality dredges used for contaminated sediment clean up.

Three possible ACCORD functions were discussed, along with the respective estimated funding that each level would require.

The first possible function of ACCORD is to be an information clearinghouse. A website containing sampling protocols, the ACCORD *Research Framework*, and past papers and presentations would be constructed and managed. New papers and presentations would be supported, annual meetings organized, and software disseminated. Updates on dredging-resuspension monitoring activities would also be provided.

An enhanced second level of ACCORD function was then presented. In addition to information distribution, the organization would also oversee updating monitoring protocols as new information becomes available, actively work with other government agencies/private groups to develop guidance and regulations, work with monitoring organizations to recommend improvements and identify collaborators.

The third level for ACCORD discussed added the role of performing technical review of proposals and the distribution of funds for research.

The establishment of a steering committee and advisory committee for ACCORD was presented, along with proposed meeting schedules. The meeting concluded with an informal show of hands regarding the usefulness of ACCORD and the probable participation of attendees' organizations. The overwhelming majority, in both cases, was affirmative. ACCORD is therefore moving forward with website development and follow-up communication with interested parties from the WEDA meeting.

The meeting was attended by:

Name	Organization	Phone	email
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## **Appendix 1**

### **ACCORD CHARTER**

**Draft presented at WEDA 24, Orlando, July 2004**

# **ACCORD CHARTER**

## **Draft presented at WEDA 24, Orlando, July 2004**

### **1. ACCORD Charter/Mission**

- a. The Advise and Consultation **Committee** on Resuspension due to Dredging (ACCORD) acts as an advocate for technically sound, risk-based management of dredge-induced resuspension of sediments. ACCORD interests include all types of dredging: capital (new work), maintenance, and contaminated sediment cleanup. Key issues of concern to ACCORD include environmental windows and contaminated sediment clean-up residuals.
  - i. ACCORD supports research where the ultimate goal is to eventually develop the ability to predict resuspension from all the major dredge types, over a full range of hydrodynamic regimes and sediment types.
  - ii. A second goal is to also include the ability to predict resuspension for a wide range of specialty dredges used for contaminated sediment clean up.
- b. ACCORD will provide a recommended research framework that can be used by decision makers to optimize funding of research on dredge-induced resuspension of sediments (perhaps expanding to include resuspension of sediments due vessel passage).
- c. ACCORD will consult on developing technology for predicting resuspension due to dredging, primarily focusing on models to predict resuspension rates, protocols for measuring resuspension levels, and collection of data that can be used to develop/verify models.
- d. ACCORD will provide guidance to government agencies and other organizations that are developing regulatory guidance on resuspension of sediments due to dredging.
- e. ACCORD will provide technical transfer of information on dredge induced resuspension, including the following:
  - i. Monitoring protocols (for both model verification/development and regulatory compliance)
  - ii. Software for predicting resuspension
  - iii. Technical guidance
  - iv. Case studies (database of resuspension data?)
  - v. Literature on physical/biological impacts
  - vi. Papers and presentations

### **2. ACCORD Background/Proponents.**

- a. Resuspension of sediment in the water column continues to be a topic of interest to the U.S. Army Corps of Engineers (USACE), U.S.

Environmental Protection Agency (EPA), U.S. Minerals Management Service (MMS), state resource agencies, and other stakeholders worldwide. For example, the Corps has funded research on all aspects of resuspension during dredging since the 1970's, and recently the MMS has funded substantive research on offshore sand and aggregate dredging. Dredging contractors and government agencies in the Netherlands are also funding research on resuspension, with other European countries showing interest in accurate predictions of resuspension due to dredging as a basis for sound regulatory policy. In addition, the EPA has funded research on resuspension of contaminants during clean-up dredging and continues to fund research on contaminant interactions with sediment particles.

- b. Such extensive interest in resuspension due to dredging is based on the many potential negative impacts on biological resources and their habitats. Resuspension of sediment is a concern during maintenance dredging, mining of sand for beach nourishment, and especially during clean-up dredging of contaminated sediment. There is a need to develop high-quality models that predict resuspension. Data from such models will allow agencies to base dredging regulations on sound science and rigorous engineering. At present, regulations in many areas have little or no scientific basis. In many locations restrictions on dredging due to perceived impacts from resuspension are severe, although effectiveness of the restrictions themselves in providing desired protection cannot be readily measured. In contrast, cases still exist where dredging is conducted with few or no restrictions in ecologically sensitive areas and restrictions may indeed be justified.
- c. In 2001, personnel from the US Army Engineer Research and Development Center (ERDC) and HR Wallingford initiated a cooperative effort to develop improved models for predicting resuspension of sediments due to dredging. This effort supplemented an existing contract between the Dutch Rijkswaterstaat and a consortium of Dutch dredging contractors (VBKO) who were funding HR Wallingford and Dredging Research Limited (DRL) to develop improved models of resuspension. In January 2003 in Herndon, VA, a workshop on resuspension of dredged material was held. The purpose of the workshop was to allow U.S. participants from the Corps, EPA, MMS, and collaborating partners from the US and abroad (HR Wallingford, DRL, Rijkswaterstaat) to learn the history, goals, status, and plans of each group's research efforts. Attendees included government, academia and private sector representatives.
- d. The outcome of that meeting was a decision to develop a research framework to assist decision makers in setting priorities and allocating funds for resuspension research.
- e. As scientists and engineers have discussed the complexities of research on resuspension of dredged material, it has become obvious that a genuine need exists for an organization that provides advocacy, sound information, guidance and technical transfer. Thus ACCORD was



initiated, with the first meeting held in London in October 2003. During that meeting strong support for the ACCORD principles was expressed. A subsequent meeting in Vicksburg, Mississippi, held in May 2004, further discussed how ACCORD would function.

### **3. ACCORD Status**

- a. Pursuant to the May 2004 ACCORD meeting in Vicksburg, it was decided to discuss ACCORD in an open forum at the Texas A&M (TAMU) Dredging Seminar/Western Dredging Association's (WEDA) Annual meeting in Orland, Florida, in July 2004. The goals of the ACCORD Meeting at TAMU/WEDA are to inform the dredging and regulatory community of ACCORD objectives and gain additional support for and participation in this endeavor. Some topics for discussion at that meeting follow.

- b. **ACCORD Functions.**

- i. Functions provided by ACCORD will be greatly influenced by funding support. As funding will likely be limited initially, present thoughts are to make ACCORD primarily a "clearing house" of information. Later, expansion of ACCORD's role could occur.

- 1. Information Distribution (Clearing House) Products**

- a. Manage an ACCORD Web Site which will provide
        - i. Monitoring protocols
        - ii. Past papers and presentations
        - iii. Research framework
      - b. Provide updates of resuspension monitoring activities
      - c. Support new papers and presentations
      - d. Facilitate dissemination of resuspension software
      - e. Organize annual meetings
      - f. Funding for this level of effort will be relatively modest, with a major portion of the funding potentially coming from the USACE Dredging Operations Technical Support program. An outside group to manage funds from sponsors and distribute funds is needed.
      - g. Estimated annual funding level, approximately \$100K.

- 2. Information Distribution/Regulatory Guidance/Research Advice.**

- a. This represents an enhanced level of ACCORD activity. In addition to the information distribution functions, ACCORD would perform the following activities:
        - i. Oversee updating of monitoring protocols as new information becomes available.

- ii. Actively work with other government agencies/private groups to develop guidance and regulations.
- iii. Work with organizations performing monitoring activities, recommend improvements, and identify potential collaborators.
- b. Estimated funding requirements approximately \$200K.

### **3. Research Coordination and Review and Funding Distribution**

- a. This level adds the roles of performing technical reviews of proposals and distributing funds for research. This would necessitate implementation of a formal organizational structure and guidelines to accommodate funding mechanisms.
  - i. A major new task involves active solicitation of funds from various organizations and sources with vested interests in data collection and/or model development.
  - ii. Proposals for research would be technically reviewed and recommended for funding.
  - iii. Experience to date has shown that a thorough and rigorous monitoring of a dredging event with sufficient manpower, vessel support, instrumentation to cover reasonable spatial and temporal scales, data analysis, and publication of results costs on the order of \$250K. In some cases it may be possible to supplement an existing monitoring effort (funded by another organization) to get data of sufficient quality at a lower cost.

#### **c. Internal Structure.**

- i. The internal structure of ACCORD will depend to some degree on the level of activity. A proposed basic structure is as follows:
  1. **Steering Committee.** This would be a group of 5 to 10 knowledgeable scientists/engineers who perform the majority of the work of ACCORD. This committee will meet periodically to discuss technical issues. Some administrative assistance would be required.
  2. **Advisory Board.** The Advisory Board will periodically review information and recommendations from the Steering Committee on research projects involving new

models and protocols, and provide directions for future research. Advisory board members would consist of the major sponsors and organizations funding ACCORD.

- d. **ACCORD Membership.** Initial discussions considered making ACCORD a world-wide organization, initially focusing on the US and Europe. However, difficulties in receiving endorsements from various European governmental organizations has lead to a decision to construct ACCORD initially as a US-led organization. The following agencies, organizations and groups are potential members of ACCORD.

- i. US Federal Agencies
  1. USACE (HQ, ERDC laboratories, some Districts)
  2. EPA (OSWAR/Superfund)
  3. MMS (Outer Continental Shelf Mining Group)
  4. NMFS
- ii. US State Regulatory Agencies and related sub-groups
  1. Contaminated Sediment Task Force (Southern California Group)
- iii. US Dredging Contractors and advocacy groups (DCA, WEDA)
- iv. International Dredging Contractors and advocacy groups (e.g. IADC)
- v. Navigation Advocacy Groups (PIANC, etc.)
- vi. US Major Ports and Advocacy Groups (AAPA)
- vii. Advocacy groups for contaminated sediment clean-up (e.g., SMWG)
- viii. Contractors and consultants

#### 4. ACCORD Funding Sources

- a. Clearing House/Basic Administrative Funding
  - i. These funds will pay primarily for the work of the steering committee. Funds will include steering committee labor, travel, miscellaneous office expenses, meeting expenses, and technical transfer (primarily web site development and maintenance)
  - ii. Potential Administrative Funding Sources include the following
    1. The National Science Foundation (NSF) has previously supported start-up administration of similar efforts
    2. USACE (some funding will go directly to ERDC members who are participating and some to the ACCORD parent organization (e.g., PIANC, NSF)). The USACE Dredging Operations Technical Support (DOTS) program is a potential source, particularly for web site development and maintenance.
    3. EPA (OSWAR /Superfund)
    4. MMS (Outer Continental Shelf Mining Group)
    5. NGOs (e.g., DCA, EuDA, SMWG, Contaminated Sediment Task Force)
    6. Major Ports (individually or via AAPA)
    7. Major Dredging Companies or advocacy organizations (DCA, VBKO, CEDA, WEDA)

8. European Government Organizations
  - a. Rijkswaterstaat
  - b. DEFRA (UK)
- b. Research Project Funding
  - i. The SSB (a consortium of major Dutch dredging contractors) is funding five hopper dredge monitoring efforts over the next three years and associated model development.
  - ii. Potential funding sources for research projects
    1. Port Authorities
    2. USACE (Dredging Operations and Environmental Research Program)
    3. Major Dredging Companies/Dredging Advocacy Groups
    4. SMWG
    5. Other NGOs (e.g., Contaminated Sediment Task Force in Southern California)
5. ACCORD will function by
  - a. Continued communication/periodic (issue-based) meetings of technical groups
    - i. Face to face (six month interval)
    - ii. Teleconference (three month intervals)
  - b. Periodic meetings of steering committee and advisory board (annually)
  - c. Larger meetings of sponsors/members will typically be held in association with other meetings, e.g., WEDA Annual Meetings, WODCON, etc.
  - d. Interactions with government agencies
  - e. Consider using the Sediment Management Working Group as an organizational model.

## Appendix 2

### **FRAMEWORK FOR RESEARCH LEADING TO IMPROVED ASSESSMENT OF DREDGE GENERATED PLUMES**

T. N. Burt and D. Hayes

# FRAMEWORK FOR RESEARCH LEADING TO IMPROVED ASSESSMENT OF DREDGE GENERATED PLUMES

T. N. Burt<sup>1</sup> and D. Hayes<sup>2</sup>

## ABSTRACT

At a meeting held in Washington DC in January 2003 a number of organisations in the USA (including USACE and EPA) and Europe recognised the need for a more structured approach to conducting research into the generation and impact of sediment released by dredging. The authors were commissioned to produce a framework for research and presented some of the preliminary findings at WEDA XXIII. The paper reflects the review so far by the authors and takes into account initial comments received.

The aim of the research was to produce a framework of the steps and knowledge needed to properly assess dredge-generated plumes. This begins with improving knowledge of the source term and finishes with real impact assessment. For each item identified, the state of knowledge that already exists is being reviewed and this is leading to identifying what further research (if any) is needed.

Having completed the framework an attempt will eventually be made to prioritise what research is most needed and will achieve the greatest initial contribution to the assessment procedure. In this way it is to be hoped that future research funding may be well-targeted and that it will be possible to better protect the environment without the need to invoke the precautionary approach quite so often, which sometimes results in possibly unnecessary expense or restriction on development.

The research presented in this paper is still in progress and the paper is to some extent an invitation to contact the authors with information that will help in setting priorities for research. The scope of the paper has also been focused primarily on the physical processes involved and their impacts. The research will also include contaminant release and impacts and it is hoped to present this in a future paper.

**Keywords:** Dredging, re-suspension, turbidity, impacts, research.

## INTRODUCTION

There are two types of driving force that urge us to assess the effects of dredge-generated plumes, a genuine concern for the environment and the regulations that forbid us to dredge unless we can demonstrate that harm will not be caused to the environment. Ideally the two will work hand-in-hand but sadly this is not always the case. A brief summary of the latter pertaining to the USA and Europe is given first. The remainder of the paper is then devoted to the research.

### London Convention 1972

The London Convention is a global convention with about 90 member countries. Members agree to introduce legislation in their own countries in order to implement the Convention. The aim of the Convention is to protect the marine environment. Its application is limited to non-territorial waters although many countries choose to apply it to their territorial waters, including estuaries.

Impact assessment is supposed to include potential effects on human health, living resources, amenities and other legitimate uses of the sea. It has to define the nature, temporal and spatial scales and duration of expected impacts based on reasonably conservative assumptions.

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At present the Convention covers only deliberate placement of dredged material in the sea. Some parties would like to see the scope of the convention increased to include regulation of the dredging process and the geographical boundaries extended. A paper presented by The Netherlands (LC 72, 2003) put forward a number of options about this but there was not much enthusiasm from most other parties for a major change in the scope. OSPAR is going through the same discussion.

### **OSPAR Convention**

OSPAR functions in a similar way to the London Convention but only applies to countries bordering the North Sea and North East Atlantic. It too has dredged material guidelines that are very similar to the LC guidelines for dredged material and there is little value in repeating the above discussion.

More significant is that OSPAR is more enthusiastic about moving towards regulating dredging operations. A working group is in the process of preparing papers covering the effects of capital works, maintenance works and aggregate dredging. This is at an early stage so it is not possible to be precise about what new regulatory processes may emerge. However, it would be wise to take into account in any research the possible need to monitor dredging operations in addition to disposal. Most, perhaps all member countries apply OSPAR to their territorial waters.

### **EC Water Framework Directive**

The European Community's Water Framework Directive (EC-WFD) came into force on 22<sup>nd</sup> December 2000 and now has to be incorporated into national legislation in the Member States. Its aim is to bring about co-ordinated management of water systems, extending beyond national and state boundaries. It is expected that the Directive will stimulate an all-embracing approach to water protection with a stronger ecological focus and that, in addition, economic considerations will increase in importance.

The Directive will affect the way that dredged sediments are handled.

The EC-WFD mentions themes of dredging and dredged material only indirectly, in Appendix VIII, in the sense that "suspended solids are some of the most important harmful substances". Those who are experts in dredging and dredged material know that suspended solids are an essential part of the biological system of a river and will naturally become sediment in the river at some later stage further down stream. Eventually, this sediment will appear to dredging operators downstream as "material to be dredged".

In future, bodies of water are to be managed according to standardised principles and objectives in relation to river basins, i.e. all the way through from tributaries to coastal waters. Administrative and state boundaries will no longer be relevant.

A good ecological and chemical status is to be achieved within 15 years in the case of surface waters, and a good ecological potential and good chemical status is to be achieved in 15 years in the case of heavily modified or artificial water bodies. In addition, the ban on deterioration will apply.

In Annex X, the Directive contains a list of 32 priority substances, 20 of which accumulate in the material in suspension or in the sediment. Apart from known parameters such as mercury and cadmium, the list also includes new, previously less well-known groups of substances.

### **Environmental Windows**

The US National Academy held a workshop in Washington DC in March 2001, resulting in "A Process for Setting, Managing and Monitoring Environmental Windows for Dredging Projects" (NAS 2002). On behalf of CEDA Neville Burt carried out a review of the windows concept as it is being considered or applied in Europe. The following is based on extracts from the resulting paper (Burt 2002).

One factor is common in the comments of those consulted, that there are inherent problems in the concept which may not only unreasonably restrict dredging operations (with consequences for social and economic costs) but may actually increase the risk of environmental harm.

In the USA the concept of Environmental Windows was introduced about 30 years ago and now about 90% of civil and maintenance dredging works are confined to specific periods of the year.

In Europe, until recently the majority of dredging operations have been allowed to proceed all year round. However since the introduction of the EU Directives for the conservation of Natural Habitats

and the protection of birds (Habitats Directive and Birds Directive) the effects of dredging operations have and are being considered in more detail leading to the idea of introducing the concept Environmental Windows.

Whilst Environmental Windows appears to be a simple tool to limit the environmental impacts, people directly involved in environmental dredging issues in Europe are concerned at the severity with which it is being applied in the US and would seek to avoid such problems in Europe. The concept places a great deal of pressure on those promoting a dredging operation to prove that it will not cause harm to the environment. Scientifically this is a very difficult thing to do. All of this results in critical standards or windows being set based on something that is not yet capable of being measured or predicted and the actual environmental impact of which is hardly known.

In the face of these things the only solution would seem to be research to gain a better understanding of the real effects of dredging as opposed to the perceived effects, and further investigation into ways of mitigating those impacts. It will also be essential to communicate the results of the research in an effective way so that policymakers, decision makers and stakeholders understand and accept them.

## **REVIEW OF MECHANISMS OF SEDIMENT RELEASE**

The mechanisms of sediment release by dredging operations have been presented previously (Burt and Land 2003) and to those involved they have become fairly familiar. However, quantifying them is another matter. Models of source terms have been produced (e.g. TASS, (Burt et al. 2000)) but remain largely uncalibrated. The problems are the lack of a consistent definition of sediment release, the practical difficulty of taking measurements, identifying suitable opportunities and the cost of obtaining the measurements.

To try to gain international co-operation in obtaining calibration data two initiatives have been taken, the production of a protocol for taking measurements (HR Wallingford and DRL, 2003) and the setting up of a co-operation group called ACCORD (Advice and Consultation Committee on Re-suspension by Dredging).

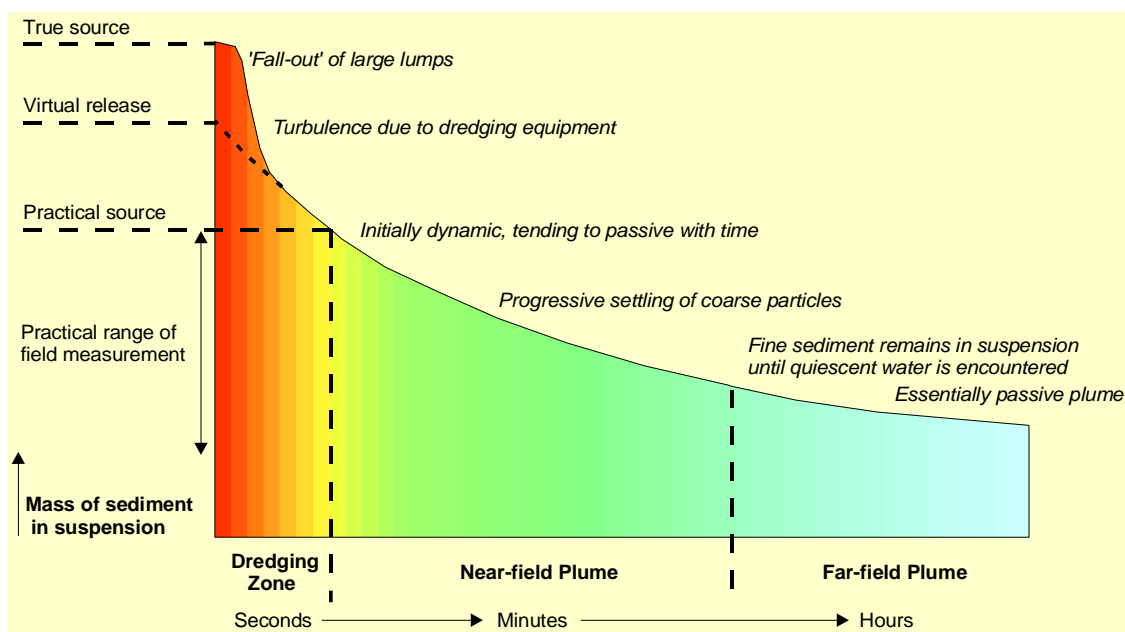
Development of the protocols was commissioned by a consortium of Dutch dredging contractors (VBKO) together with the Dutch Rijkswaterstaat. The draft protocol was circulated to selected experts worldwide and the comments received were taken into account in the version released in June 2003. It is seen as a living document and will be updated regularly in the light of practical experience. So far it has been used in Europe to monitor a trailing suction hopper dredger in Rotterdam in 2003 and a grab dredger working on the River Tees in 2000 (a brief account was given of the Tees measuring exercise at WEDA XX and an account of the Rotterdam experiment will be given at WODCON 17 in September 2004). It has also been used on the Providence River in the US in 2003.

The protocols include a definition of sediment release as illustrated in Figure 1.

The protocols are available for general use and may be obtained from the authors. It is hoped that they may soon be available on the Web.

ACCORD was initiated following a meeting in Washington DC in January 2003 organised by the US Army Engineer Research and Development Center (ERDC) (Clausner 2003). The purpose of the Washington meeting was to bring together those involved in research on sediment and contaminant resuspension. It was attended by representatives of the Environment Protection Agency, the Minerals Management Service, ERDC, other Corps of Engineers offices, academia from the USA and number of researchers from Europe. ACCORD held its first meeting in London in November 2003 and its 2<sup>nd</sup> meeting took place at the ERDC in Vicksburg in May 2004. At present it is simply a group of people with a common interest. It is thought that to be effective it needs to be more formally constituted. The main aim is to identify opportunities for measurement of sediment release using the internationally reviewed protocol and to share the knowledge gained from the results, though it may be extended as a forum for other areas of related research.





**Figure 1. Definition of sediment release.**

The sediment released or re-suspended by dredging operations should properly be seen in the context of natural variability due to river flow, wave action, etc. and the framework for research should take this into account.

Finally it should be noted that dredgers are not the only anthropogenic sources of sediment release. Shipping operations, particularly when large vessels are manoeuvring onto or off berths can cause bed sediment to be brought into suspension. This remains largely un-quantified but is likely in most situations to be a much more frequent occurrence than a dredging operation.

## REVIEW OF MECHANISMS OF CONTAMINANT RELEASE

Although many contaminants are associated with sediment they do not necessarily move or behave in the same way when disturbed by dredging.

Principally, the physicochemical environment controls the processes involved with the immobilisation and mobilisation of sediment-associated contaminants. The main sediment properties affecting the reaction of the sediment with contaminants are clay type and content, organic matter content, cation exchange capacity, reactive iron and manganese, oxidation-reduction potential (redox), pH and salinity. Of these properties, it is the clay, organic matter, pH change and redox conditions that predominantly influence the mobilisation of contaminants from the sediment.

Contaminant mobilisation occurs due to a dredging induced change in physicochemical sediment conditions. Where dredging causes a sediment plume to arise, the physicochemical environment changes considerably and substantial contaminant release can occur. This reaction is not always the case and a change in the physicochemical environment can release contaminants from the sediment yet favour other immobilising reactions.

There are various contaminants that pose a risk to the marine environment. The main contaminant groups include heavy metals, hydrocarbons and organochlorine compounds. In addition, there are other specific contaminants of environmental concern such as tributyl tin (TBT), the biocide agent used in anti-fouling paint formulations. The environmental effect of each contaminant differs, depending upon the receiving environment, but contaminants are often discussed in terms of their toxicity, ability to bioaccumulate and environmental persistence.

## **HEAVY METALS**

Metals enter the aquatic environment from both natural and anthropogenic sources. Trace amounts of metals arise from the weathering of rocks and soils. Natural contributions can be high in areas of metal ore bearing strata. Large quantities of metals enter the environment through diffuse sources such as run-off and atmospheric deposition in addition to point sources such as domestic and industrial wastewater discharges. Metals are used in many industries including manufacturing processes and as chemical catalysts.

Metals discharged into the naturally turbid estuarine water can be rapidly bound onto the surface of fine suspended sediment particles, by various adsorption processes. As the suspended sediment settles to the bed, the associated metals are gradually buried and become immobilised in anoxic sediment conditions.

Metals (and other contaminants) are of concern because of their toxicity, persistence and tendency to bioaccumulate in living organisms. In addition to the amount of a metal present, toxicity depends upon the degree of its oxidation and the form(s) in which it occurs. The ionic form of a metal is generally the most toxic (eg. cadmium  $2+$ ). Toxicity can be increased if the metal is complexed with natural organic matter. Metallo-organic compounds such as methyl-mercury form under certain natural conditions and exhibit greater toxicity than inorganic elements alone.

A metal's ability to remain in the environment is known as its persistence. Unlike some organic substances (ie. hydrocarbon and organochlorine compounds), metals tend not to decay at any appreciable rate and therefore can remain indefinitely within the aquatic environment.

Aquatic organisms may bioaccumulate metals, depending upon the organism's physiology and the degree of metal bioavailability. Bioaccumulation is the ability of an organism to accumulate contaminants in body tissues. Depending on the degree of bioaccumulation and the sensitivity of the particular organism, accumulated contaminants can cause toxic effects such as tumours, bodily deformation and even death.

## **HYDROCARBON AND ORGANOCHLORINE COMPOUNDS**

There are many types of hydrocarbon compounds and organochlorine (OCl) compounds that can adversely affect the marine environment. The compounds most commonly occurring in dredged material are polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and OCl pesticides.

In the aquatic environment, PAHs are found at low concentrations in water due to poor aqueous solubility. However, they are easily adsorbed to organic matter and inorganic particles in the water column and, should local sources exist, are likely to arise in deposited river silt.

In the aquatic environment, PCBs tend to be adsorbed quickly by organic matter due to their hydrophobic nature.

Unlike many other contaminants, OCl pesticides are designed by manufacturers to be distributed in the environment, supposedly targeting a particular pest.

## **OTHER CONTAMINANTS**

Tributyl tin (TBT) is often of concern during dredging projects. Since the discovery of its biocidal properties in the 1950s, the industrial application of TBT includes its use as the biocide agent in anti-fouling paints and coatings, molluscicides and agricultural fungicides. TBT enters estuaries from a limited number of point sources including dry docks and marinas, and many diffuse sources such as vessel hulls.

Because of its hydrophobic nature, once in the water column TBT readily comes out of solution and adsorbs to particulate matter and sediment. TBT also binds with phytoplankton, thereby introducing it to one of the lowest levels of the food chain.

## CONTAMINANT MOBILISATION BETWEEN SEDIMENT AND WATER

The risk of contaminant mobilisation affecting water quality and having subsequent environmental effects on aquatic life needs to be put into context with regard to the partitioning behaviour of individual contaminants. Contaminants have different degrees of solubility. Metals, such as lead, are quite insoluble and their partitioning from sediment is largely controlled by changes in pH. The potential for contaminant partitioning from the sediment to water can be measured through laboratory research. For example, sediment-water partition coefficients for TBT vary considerably, but are mainly in the order of 10<sup>3</sup>-10<sup>4</sup> (Waldock et al., 1990). It should, therefore, be recognised that many of the contaminants mobilised by dredging actually remain bound to re-suspended sediment rather than become dissolved into the surrounding water (limiting their potential impact). The environmental impact of mobilised contaminants is more of a concern after sediment plumes have settled on the seabed.

## IMPACTS

In the research here described the environmental effects have been related, as far as possible, to different types of dredging project, sediment types, plume types and dredgers. Short-term and long-term effects have been identified, highlighting how sediment plumes affect the water column and seabed in different ways and the influence of natural variability on this.

The baseline dataset must cover natural variations and seasonal patterns in order to provide the context within which to determine if a change constitutes an impact. A variety of factors need to be investigated in order to make predictions regarding the effects of dredging, including a knowledge of existing water quality, biological communities, substratum, fisheries and shellfisheries resources.

It is important to determine the thresholds of acceptability in any particular environment, in terms of the tolerance of the species present, and to relate this, for example, to the environmental change caused by the re-suspension and movement of a sediment plume, particularly the concentration of re-suspended sediment that can be tolerated over the background concentration. Such thresholds will be site specific and species specific. Some fish species are tolerant of turbid water conditions and so dredging induced increases in turbidity might not cause a significant long-term effect.

In essence, therefore, in order to determine whether an effect constitutes an impact, information is firstly needed on the plume's concentration and its footprint, secondly on the duration of the plume and thirdly how this compares to background levels and the tolerances of the species present.

The environmental effects associated with sediment plumes tend to occur as a result of two types of direct physical environmental change. Chemical changes can also occur if the sediment in the plume changes physicochemical conditions by reducing dissolved oxygen levels or introducing toxic contaminants to the marine environment.

The first physical change is associated with the presence of the sediment plume in the water column, which increases the concentration of suspended sediment in the affected water. In the context of marine biological resources, the effect of a sediment plume in the water column depends greatly on background suspended sediment concentrations and the ability of marine life to either cope with or adapt to a change in conditions.

The second change occurs when the sediment plume settles out of suspension, thereby changing the environmental conditions of the seabed. Denser, deeper sedimentation might occur when a dynamic plume reaches the seabed compared to shallower, dispersed sedimentation from a passive plume. In the context of marine biological resources, the effect of sedimentation on the seabed depends greatly on the existing substratum and the ability of benthic life to either cope with or adapt to changed conditions.

## RESEARCH FRAMEWORK

Since the aim of the research framework is to identify and prioritise areas where research is needed to be better able to assess the effects of dredge resuspension it seems logical that the framework should be based on an assessment framework. This will help to identify what we need to know to improve confidence in our decision making. Prioritisation can then be based on a more “joined up” approach than simply choosing things that we would like to study because they are interesting.

The assessment framework does not need to be complicated. In broad outline it consists of a number of basic questions. Of course this may lead to much more in-depth questions that can be difficult to answer.

A general assessment framework is given in Figure 2 and a draft research framework is given in Figure 3. It is a logical breakdown of the questions that we need to answer in making an assessment, the mechanisms (in very simple form) that we believe have the potential to bring about an impact and the tools that are either available or need to be developed to give quantitative predictions of impacts.

## PRIORITIES

It is not possible in the context of this paper to give a full priority assessment, partly because the information needs to be presented in a much more detailed way and partly because the review process is still underway. However, it is appropriate for the authors to make a few comments.

### **How much sediment is released?**

Many of the measurements made over the last 20 years have been made in still water situations. This means that any sediment falling relatively quickly to the bed is not measured and the suspended solids concentrations that are measured are those due primarily to diffusion out of the dredging area rather than advection. This suggests that release rates will be underestimated in the case of flowing water.

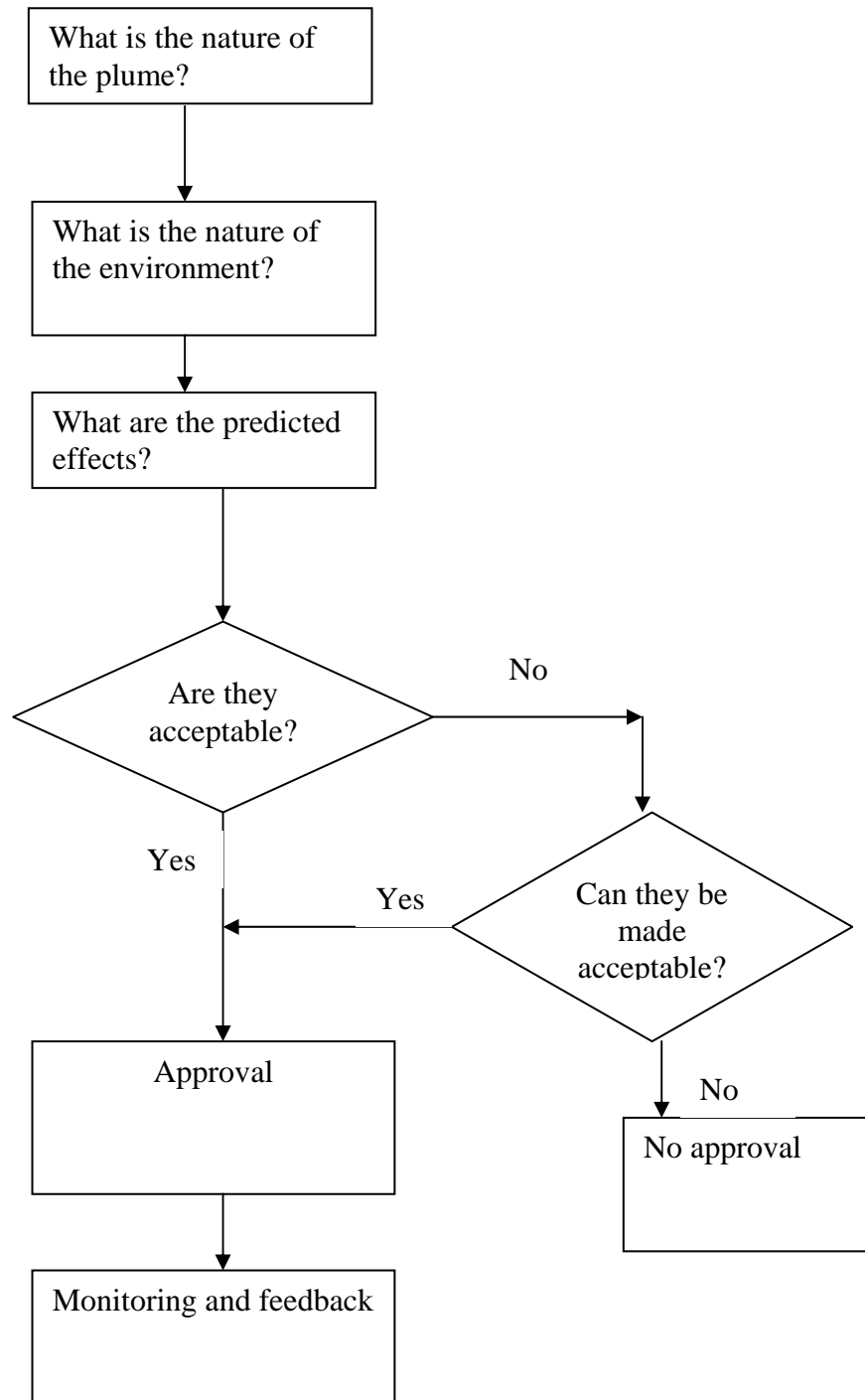
Measurements have also generally been made either with bottle or pumped water samplers or with turbidity meters. The main difficulty with water sampling techniques is the limited number of samples that it is possible to take in a plume that is transient, constantly changing in both dimension and sediment concentration. Calibration of optical systems is very poor when there is sand present in the suspension, again tending to give underestimates for any sediment coarser than silt. ADCP techniques show promise but still require a lot of effort and skill in calibration and interpretation.

Referring to the diagram of sediment release (Figure 1) it is clear that it will remain impossible to measure what happens in the “dredging zone”. The fact that material settles back into the area being dredged is not of great concern since it is already accepted that the bed in this area is being greatly disturbed. It is of more importance to know how much sediment may travel out of the dredging zone and thereby affect the aquatic environment. The definition postulates a “virtual release rate” which, although virtual is very important to know because all other aspects of the assessment process depend on it. It does require measurements to be made at several sections downstream of the dredger.

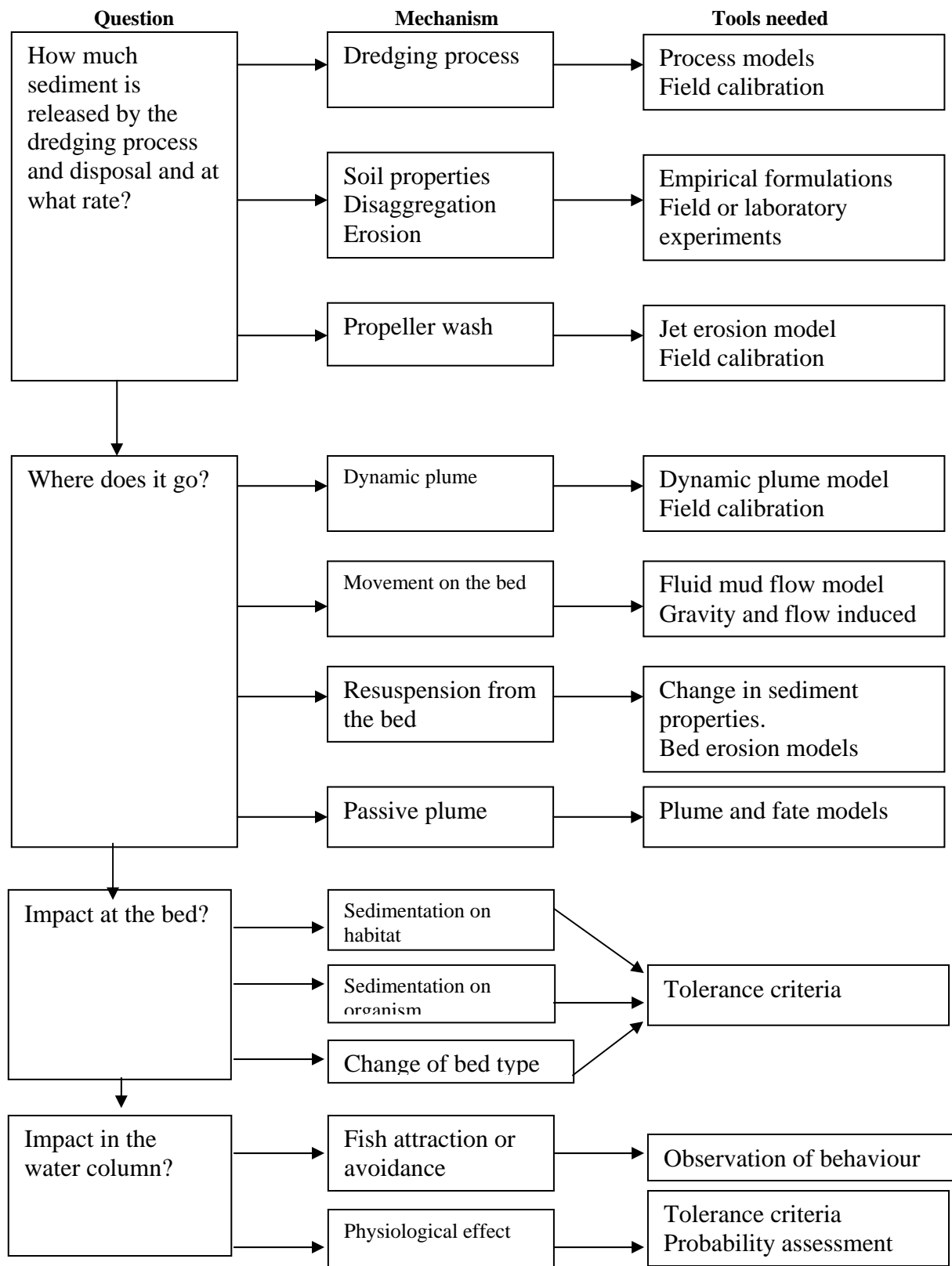
### ***Dredging process***

To study this aspect process models are needed. As stated previously some models exist but lack field calibration. This has to be regarded as a high priority because until we know how much sediment is released and at what rate, the impact assessments are based on guesswork. Additional models are needed for specialist dredgers that are used in environmental clean-up projects (Superfund projects in the US) and calibration data are needed for all of them.

Related to this is the determination of how much sediment is released by the action of the draghead in the case of a trailing suction hopper dredger. The re-suspension process is a combination of hydraulic erosion caused by turbulent kinetic energy and a bulldozing effect. The hydraulic erosion lends itself to computational fluid dynamics modelling (CFD) combined with classic bed erosion theory. A literature search has not revealed any formulations for the bulldozing effect. It does not lend itself to a purely theoretical approach and will probably require physical modelling to observe the processes taking place.



**Figure 2. A simple assessment framework.**



**Figure 3. Research Framework A – Physical Impact.**

### ***Mitigation***

It is also important to know if the rate of sediment release can be controlled by operating the plant in a special way or selecting special plant (always with a cost penalty).

Perhaps not directly relevant to the release of sediment but relevant to some projects is the use of silt screens to restrict the release of sediment from the dredging area. In the author's experience these are often specified in dredging contracts without any real knowledge of their practicality or effectiveness. Research is needed to provide guidelines for their use. Past experience on use of silt screens in almost all navigation dredging projects has shown them to be of essentially no practical value beyond aesthetics, while increasing costs and operational complexity.

### ***Soil properties***

As part of the modelling process we need to understand the way that various soils behave when subjected to dredging processes. In most cases the forces acting on the sediment are a combination of mechanical and hydraulic forces. Existing formulations tend to use the percentage fine material present assuming it all to become available for re-suspension. This does not account for properties of cohesion which, in the case of clay-size particles, is very strong. In that particular case the dredging process often results in the formation of clay balls rather than release of the very fine material. There is a need for research to identify and correlate the relevant soil properties and perhaps a new soil disaggregation test to be developed.

### ***Propeller wash***

The trailing suction hopper dredger may re-suspend sediment by the turbulence caused its propeller. Models exist for jet induced erosion but recent studies by Maynard (pers. com. 2004) have shown that the pressure wave caused by a passing vessel may actually re-suspend more material than the propeller.

The importance of both draghead and propeller re-suspension can be questioned on the grounds that in most muddy situations overflow is not efficient and often not allowed. In sandy areas where overflow improves the dredging efficiency the losses are orders of magnitude higher than those created by either the draghead or the propeller. The only relevant application is thus when dredging in sandy material in an area thought to be very sensitive to turbidity, for example in the case of coral.

Of course it is not only dredgers that resuspend sediment by propeller action or by towing equipment along the aquatic bed. Perhaps in making impact assessments the effects of dredging should be examined in the context of the effects of shipping and fish trawling.

### ***Where does it go?***

This is probably the question that has been given most attention in research, both pure and applied, to date.

### ***Dynamic plume***

The density-driven dynamic plume phase is complex but has been well researched and modelled. In the case of stationary dredgers the dynamic plume, if one exists at all, descends into the dredging zone so for reasons already discussed is probably not very important. For the overflowing trailing suction hopper dredger and especially in the case of aggregate dredgers, which also screen the material, the material may be released over a large area and could be important depending on the circumstances.

Another case where a dynamic plume forms is disposal either through pipe discharge into the aquatic environment or, more commonly, disposal on the aquatic bed by bottom dumping from a hopper.

An important factor regarding the dynamic plume is the extent to which it acts a secondary source causing a passive plume. Recent dynamic plume models include this element. However, the great lack is in calibration data to ensure that predictions are reasonably accurate.

### ***Movement on the bed***

Material spilled or placed on the bed is often in a quasi-fluid form. The dynamic plume is likely in most cases to spread out like a pancake. Models of this part of the process have been in existence for

many years. The extent of the area affected is generally quite small and the impact reasonably predictable. Because the impact is obviously significant in terms of quantity and depth of material on the bed it would be most unusual for a dynamic plume to be permitted to occur in a sensitive area. The spread of the pancake is thus not considered to be a high priority for research, except perhaps for placement of contaminated sediment in a pit.

#### ***Resuspension from the bed***

Material that has settled on the bed and whose properties have been changed by the dredging and/or disposal process may be re-suspended by hydrodynamic forces, i.e. currents and waves. Computer models exist that describe bed erosion by these processes, but what is not well known is how the properties of the material are changed between their in situ condition and in their new location. Some research has been carried out on this in the UK and in the USA using various types of field erosion devices, but more field work is needed to be able to predict the properties in advance of a project with any confidence. The research should be linked to the research recommended earlier on disaggregation. Differential settling processes are also very relevant to this aspect.

#### ***Passive plume***

Many passive plume models exist, mostly in the form of “add-ons” to hydrodynamic models. It is relatively easy to build a tracking function into a hydrodynamic model and add factors of settling and dispersion to determine the fate of the material. Whilst the models themselves are generally good they depend on the physical properties assigned to the material in suspension and once again this is probably the greatest area of weakness with them. The processes of flocculation greatly affect settling velocities. In the author’s own experience of measuring settling velocities in the field an order of magnitude of difference can exist naturally between similar materials from different locations, without the added complication of the impact of dredging plant on the sediment. (Burt 1986). Again the greatest need is for good quality field measurements of passive plumes to improve knowledge of this parameter.

It is noted that while some models do include re-suspension from the bed, others, such as SSFATE (Johnson 2000), currently do not. This is particularly relevant in some tidal situations where the only time during the tidal cycle when the turbulent kinetic energy is sufficiently low to allow settlement is at slack high or low water. The deposited material can in many cases be easily and quickly re-suspended by the accelerating flow in the next phase of the tide. Thus it is important, as in the previous section, to have a good knowledge of the relevant properties of the material (temporarily) deposited on the bed in order to predict how it will re-erode.

#### **Impact at the bed?**

##### ***Sedimentation on habitat***

Should significant deposition of sand occur in areas that have a similar sediment type, the impacts on benthic communities are likely to be small. The benthic community in such an environment is likely to be adapted morphologically and behaviourally to a dynamic environment. It is, therefore, likely to be able to cope with the disturbance caused by sedimentation and this combination is not considered a high priority for research

In gravel seabed environments, sedimentation is most likely to affect sessile species because they are unable to burrow or vertically migrate in response to an increased sedimentation rate. Sessile species include delicate organisms such as bryozoans and hydrozoans.

Sedimentation also affects filter-feeding epifauna, for example sponges. Coral and kelp forest communities are also susceptible to increased sedimentation rates ( Selby and Ooms, 1996).

The loss of key species in communities can lead to the collapse of the entire biologically-accommodated community even though individual species within the community may be apparently tolerant of environmental disturbance (Newell et al., 1998).

As shown in Figure 3 the main area of research needed is into the tolerance criteria. This applies to individual species and communities as a whole. “Tolerance” includes the ability of the species and/or community to recover because the temporary loss may have a lasting impact on species that rely on the habitat for spawning or feeding. Some research on recovery of seabed benthic communities is taking place in the UK at the present time but is still at an early stage.



### ***Sedimentation on species***

This includes direct smothering of susceptible organism life stages, such as negatively buoyant or adhesive fish eggs or larval shellfish that attach to the substrate. Most shellfish are able to cope with limited covering by sediment. Again the need is to establish reliable criteria for tolerance, including the ability to recover.

### ***Change of bed type***

This particularly applies to aggregate dredging where, for example, a gravel bed is dredged and the fine material is screened out and discharged back into the water. The benthic species that are adapted to gravel may not be tolerant of the new finer bed material. Again the need is to establish tolerance and recovery criteria.

### **Impact in the water column?**

The physical, chemical and biological processes that take place in the water column are highly complex and it is beyond the scope of this paper to attempt to list them. With regard to the potential impact of additional sediment in the water column caused by dredging the effects are not well understood and there is much speculation about the impact on fish migration (Palermo et al (1990), and Environment Canada (1994)). It seems obvious that fish have, in most practical cases, the ability to avoid a plume. Some have argued that far from avoiding a plume certain fish species are attracted to it because of the organic matter that is stirred up. This clearly requires research to clarify the issue because it has major implications on the application of Environmental Windows.

As with benthic impact the impact on the water column requires research into the tolerance of relevant species to temporarily increased sediment concentrations. This topic was recently reviewed by Wilbur and Clarke (2001). Additional research should include observation of the ability of species to tolerate natural variations such as during times of flood or storm, and other temporary elevations caused by shipping and fishing (trawling and shrimping).

## **CONCLUSIONS**

The research presented in this paper is still in progress and the paper is to some extent an invitation to contact the authors with information that will help in setting research priorities. The scope of the paper has also been restricted primarily to physical processes and impacts. The research also includes contaminant release and impacts and it is hoped to present this in a future paper.

It seems clear that there is much speculation about the impacts of sediment resuspended by dredging that is not backed by research.

From the point of view of the authors it would appear that the greatest priority is to be able to measure and predict how much sediment is actually released by dredging and at what rate. Without this basic information it is not possible to produce meaningful correlations with environmental impacts. The development, verification and calibration of models is therefore an essential stage in the development of assessment tools. Furthermore, such models are needed to determine the effect of mitigative measures such as operating existing plant in a special way or using specialist environmental dredging plant.

It is also the authors' view that research on impacts should be carried out in the context of the ability of individual species and communities to tolerate (and perhaps even require) natural variations in suspended solids concentration caused by normal variations in rainfall and tides as well as more extreme variations caused by floods and storms.

Finally, it will also be essential to communicate the results of the research in an effective way so that policymakers, decision makers and stakeholders understand and accept them. One possible mechanism for assisting in this process may be the ACCORD group that has already been referred to.

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